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FLAMING FOR WEED CONTROL IN SUNFLOWER (*Helianthus annuus* L.): RESULTS OF A FOUR-YEAR RESEARCH

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Summary

Field experiments over 4 years (1988-1991) were carried out in Central Italy in order to study the effectiveness of flaming for weed control in sunflower. The effects of two inter-row flamings (24 and 34 days after sunflower emergence), hoeing and pre-emergence herbicide (Metobromuron + Prometryn) application were compared to control (untreated). Thermal treatments were carried out by a machine provided with six burners stocked with LPG and equipped with nozzles of 0.5 mm diameter.

The results showed that hoeing and pre-emergence treatment were more effective in controlling weeds. As a matter of fact, weed fresh biomass and density were reduced by 84% and 87% respectively compared to control. Early flaming treatment reduced fresh biomass and weed density by 63% and 60% respectively.

All treatments were able to reduce viable weed seed number in the upper 20 cm of soil. Soon after sunflower harvesting, mean potential flora was 5.200 seeds per m^2, 60% lower compared to control. Pre-emergence herbicide application was the best in reducing the viable seed of redroot pigweed (*Amaranthus retroflexus* L.). Regarding common lambsquarters (*Chenopodium album* L.) and black nightshade (*Solanum nigrum* L.), results were not significantly different from those obtained with hoeing.

Yields and achene oil content obtained by flaming treatments were not significantly different from those obtained by hoeing and herbicide application.

With a gas consumption of 60 kg ha^{-1}, early flaming cost did not result higher than pre-emergence treatment (139.000 Lit ha^{-1}). In order to reduce flaming cost by 40%, on-row flaming and inter-row hoeing could be combined in one single operation.

In conclusion, flaming could be a good technique to be included in integrated or completely chemical-free methods for the control of weeds in sunflower. However, further researches are necessary for the setting-up of machines, the effectiveness of treatments and the cost of flaming application in different areas of cultivation.

Introduction

Sunflower weed infestation, as many other crops, mainly depends on rotation, soil type, climate and time of sowing. In Central Italy sunflower is grown in rainfed conditions and sowing usually takes place in the first half of April. A wide range of thermophile weed species thrive in this area both grasses and broadleaves such as: *Echinochloa crus-galli* (L.) Beav., *Digitaria* spp. Haller, *Cynodon dactylon* (L.) Pers., *Solanum nigrum* L., *Amaranthus* spp. L., *Portulaca oleracea* L., *Polygonum persicaria* L., *Mercurialis annua* L. and *Convolvolus arvensis* L. (Tei, 1986).

P. Casini: data processing. P. Calamai: data recording.
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Data interpretation and draft of the manuscript must be attributed to P. Casini and V. Vecchio.

Herbicide application is the most widespread method in order to control sunflower weeds. Yet, in Italy, about 25% of the area under sunflower cultivation in the first half of the heighties was hoed (Laureti, 1985).

In the last decade, the reduced use of herbicides has become a necessity in order to limit environmental pollution and to safeguard human health. Some results on hoeing in sunflower carried out in Central Italy (Vannozzi and Salera, 1986; Pirani, 1989) have shown how this technique could effectively replace the use of chemicals in weeding. However, hoeing does not bring any yield increase if it is carried out as an integration in the herbicide application or if it is combined with ridging (Pouzet and Regnault, 1982; Covarelli and Tei, 1984; Salera, 1986).

Reduction of active ingredients for sunflower weeding could be obtained with the early preparation of seed bed and with on-row pre-emergence herbicide application (Rapparini, 1989).

Flaming (or flame cultivation) is a physical method of weed control. Ultra-short wave radiation, laser radiation, gamma radiation and thermal radiation can be used. However, only thermal rays in the form of flame, steam, hot air or infrared radiation are of practical importance (Sanwald, 1977; Vester, 1984). At present, weed control by flaming is mostly used in vegetables by organic growers. Positive results in controlling weeds in soybean, cotton and corn are reported by several authors (Knake, 1965; Sloane 1968; Matthews and Smith, 1971; Vecchio *et al.*, 1989; Casini *et al.*, 1991).

In this paper, investigations on the effectiveness of flaming in sunflower are reported.

Materials and methods

A four-year experiment (1988-1991) was conducted in Central Italy at the Agricultural Research Station of Regione Toscana (Arezzo). The soil was sandy-loam containing 55% sand, 18% silt, 27% clay with a pH of 8.0 in the top soil.

The effects of two different times of inter-row flaming, hoeing and pre-emergence herbicide (Metobromuron + Prometryn) application were compared to control (untreated).

Hoeing operation was carried out by hand while thermal treatments by one-row machine with 6 burners stocked with LPG, each burner being equipped with one nozzle (0.5 mm diameter). The first and second flaming treatments were carried out with gas pressure of 2.0 and 2.6 bar respectively, and at a speed work of 2.0 and 1.6 Km h^{-1} respectively.

The experimental design was a completely randomized block with four replications. With the exception of the first year, weed density was determined before post-emergence treatments. Counts were made of seedlings present in a 50 x 50 cm quadrat placed randomly three times in each plot. Means were expressed on a m^2 basis. At sunflower harvest, weed counts were repeated and fresh biomass determined. Besides, crop density, plant height, 1000-seed weight and achene oil content were determined.

In 1990, viable weed seed number in the upper 20 cm of soil was determined in order to study treatment effect on potential flora. Seed number was defined by taking 5 soil samples in each plot twice, soon after sunflower harvesting (22.X.1990) and from ploughed soil (23.I.1991). Three germination tests were carried out in glass-house at a mean daily temperature of 25 °C. The first test, lasting 45 d, was carried out moistening periodically the soil with only water. In order to promote germination (Eagley, 1986) solutions at 0.5 and 1% of KNO_3 were distributed on the soil samples at the beginning of the second and third germination test respectively (lasted 30 d).

At the end of the experiment a combined analysis of variance over the years was carried out.

Treatment costs were calculated assuming a cost per hour of Lit 35.000 and using a tractor with four implements. For LPG consumptions of burners, we referred to those really obtained with the plot-machine. Other details on treatments and management of the experiments are listed in tables 1 and 2.

Table 1 - Management details of the experiments.

	1988	1989	1990	1991
Previous crop	Onions	Corn	Corn	Corn
Hybrid	Mirage	Florom 350	Florom 350	Florom 350
Tillage:				
ploughing	23.ii	29.x.88	27.x.89	12.xi.90
disc harrowing	03.iii,14.iv	-	03.i	24.i
subsoiling	-	16.ii	07.ii	-
rotary harrowing	26.iv,02.vi	11.iv	21.iii	02.iv
rolling	06.v	-	-	-
Plot size	8 rows wide 8 m long	8 rows wide 8 m long	8 rows wide 8 m long	8 rows wide 8 m long
Within row spacing (m):	0.7	0.7	0.7	0.7
Plot size for weed sampling:	2 rows wide 6 m long	2 rows wide 6 m long	2 rows wide 6 m long	2 rows wide 6 m long
Plot size for yield estimate:	4 rows wide 6 m long	4 rows wide 6 m long	4 rows wide 6 m long	4 rows wide 6 m long
Fertilization:				
N (kg ha^{-1})	140	140	140	140
P_2O_5 (kg ha^{-1})	120	120	120	120
K_2O (kg ha^{-1})	70	70	70	70
Date of sowing	3.vi	11.iv	04.iv	04.iv
Soil disinfectant application (kg ha^{-1} c.p.):	15 (Barral)	15	15	15
Date of emergence	13.vi	24.iv	18.iv	17.iv
Date of flowering	10.viii	03.vii	26.vi	0.7.vii
Date of harvest	18.x	22.ix	02.x	19.ix

Table 2 - Treatment details of the experiments.

Treatments	Rate (kg ha^{-1} a.i.)	Time of application (Days after emergence) 1988	1989	1990	1991
Control (untreated)	-	-	-	-	-
Hoeing	-	24	31	34	48
Flaming I	-	10	29	28	28
Flaming II	-	24	35	35	44
Chemical weed control# (Metobromuron+Prometryn)	0.60 + 1.00	-	-	-	-

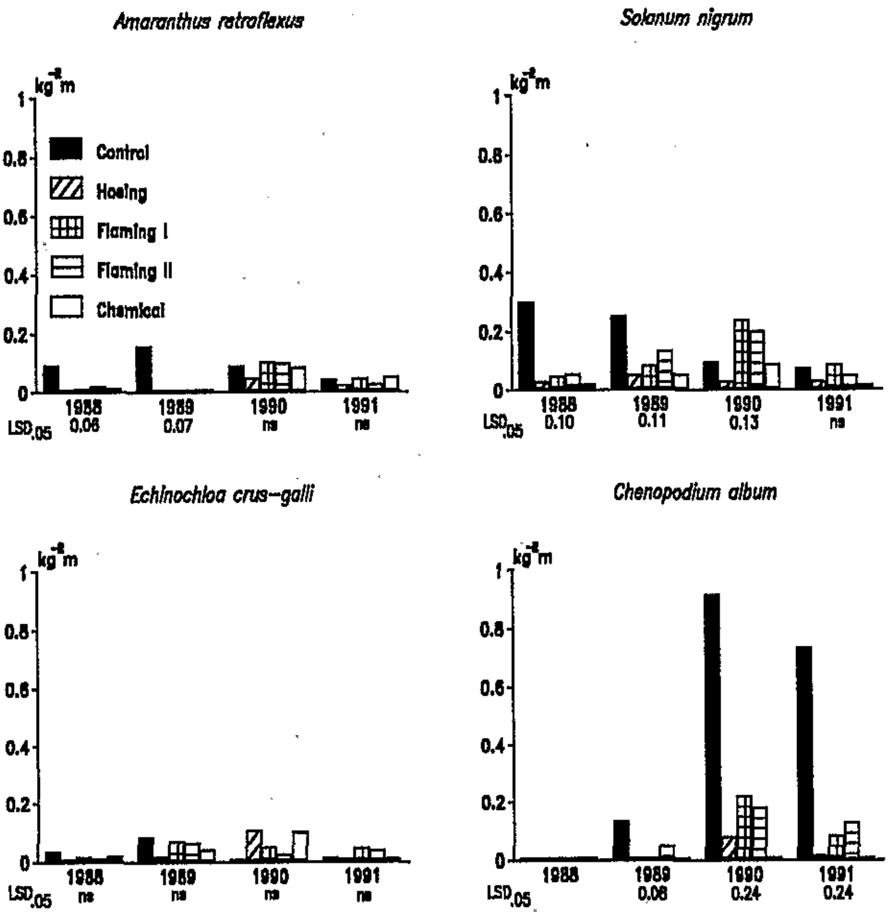
#: Pre-emergence application.

The best control of grasses and broadleaves number was obtained by hoeing and herbicide application. However, the effectiveness of flaming II on grasses was not significantly different from pre-emergence treatment.

Results on weed fresh biomass (table 4) showed the same trend described for weed density. Hoeing and chemical control caused a mean reduction of biomass by nearly 83% compared to control, while flaming reduced biomass by 63%.

In 1988 and 1989, all treatments reduced fresh biomass of *A. retroflexus* while, during the other years of experiment, any significant difference were observed (figure 2).

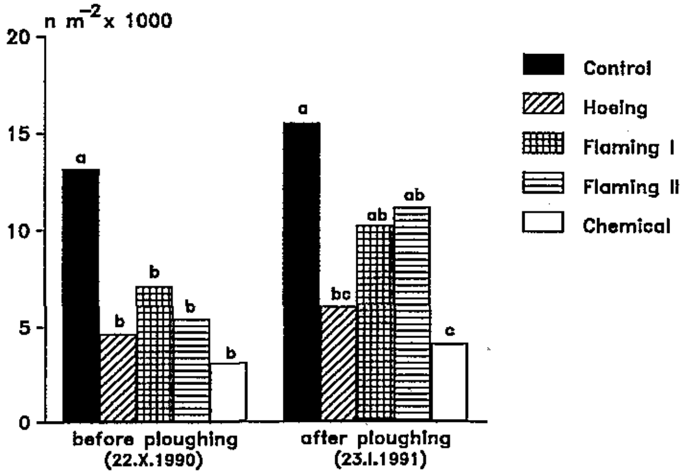
Figure 2 - Effect of treatments on fresh biomass of *A.retroflexus*, *C.album*, *E.crus-galli* and *S.nigrum*.



Fresh biomass of *S. nigrum* was reduced by 94% and 60% in 1988 and 1989 respectively. In 1990 *S. nigrum* was not controlled by flaming applications. Results on fresh biomass of *E. crus-galli* showed the same trend described for *A. retroflexus*. Yet, barnyardgrass was not controlled by hoeing in 1990. The high fresh biomass of *C. album* recorded in 1990 and 1991 (0.92 and 0.71 kg m^{-2} respectively) was significantly reduced by all the treatments. In particular, flaming application reduced fresh biomass by nearly 85% compared to control.

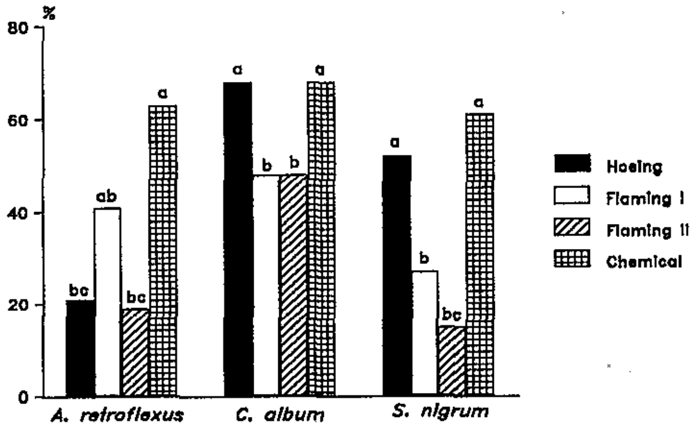
The average of weed viable seed number in the upper 20 cm of soil, soon after sunflower harvesting (figure 3), was 6.700 seeds per m^2. After ploughing, seed population increased up to 9.600 seeds per $m.^2$. Before ploughing all treatments caused a mean viable seed number of 5.200 seeds per m^2, lower than 60% compared to control. After ploughing, the lowest viable seed number was found in the chemically weeded plots with 4.500 seeds per m^2, and this value is 25% and 55% lower than that obtained with hoeing and flaming treatments respectively. Thermal treatments increased weed seed number per m^2 by 40% and 85% for late and early flaming respectively compared to the seed number determined at sunflower harvesting.

Figure 3 - (Exp. 1990).Effect of treatments on viable weed seed number of the upper 20 cm of soil recorded after sunflower harvesting (22.X.1990) and after ploughing (23.I.1991). Treatments with the same letter(s) are not different at 0.05 level (Duncan's Multiple Range Test).



Treatments modified the reduction of weed viable seeds compared to control (figure 4). The best reduction of *A. retroflexus* seeds was obtained with herbicide application and with chemical control and hoeing for *C. album* and *S. nigrum*. With regard to these last species the reductions were of 68% and 61% for pre-emergence treatment and 61 and 52% for post-emergence applications, respectively. Hoeing and flaming treatments did not bring about significantly different results regarding to *A. retroflexus*.

Figure 4 - (Exp. 1990).Effect of treatments on per cent reduction of viable seed number of *A.retroflexus*, *C.album* and *S.nigrum* in the upper 20 cm of soil, compared to control. Treatments with the same letter(s) are not different at 0.05 level (Duncan's Multiple Range Test).



Treatments did not change crop height, density and the 1000-seed weight. The mean values were 159 cm, 6 plants per m^2 and 49 g respectively.

During the experiment, crop yield and achene oil content obtained with flaming were not significantly different from those obtained with hoeing and herbicide application (table 5)

Table 5 - Effect of treatments on yield and achene oil content.

	Yield (t ha^{-1})				Achene oil content (%)			
Treatments	1988	1989	1990	1991	1988	1989	1990	1991
Control	3.6 a	4.3 b	1.9 a	3.6 a	49.7 a	44.3 a	46.9 a	52.9 a
Hoeing	3.8 a	4.6 a	2.3 a	4.2 a	49.4 a	45.1 a	45.6 a	49.9 a
Flaming I	3.8 a	4.5 a	2.0 a	3.9 a	48.9 a	45.5 a	48.6 a	51.1 a
Flaming II	3.7 a	4.4 ab	1.9 a	4.1 a	49.0 a	44.5 a	48.9 a	51.7 a
Chemical	3.9 a	4.6 a	2.4 a	4.1 a	48.1 a	44.0 a	47.4 a	51.1 a
Mean	3.8	4.5	2.1	4.0	49.0	44.7	47.5	51.3
$LSD_{.05}$ over the years		0.2					1.3	

Means within rows followed by the same letter(s) are not significantly different at 0.05 level (Duncan's Multiple Range Test).

Significant differences were observed regarding the annual mean values. Average yields per hectare were 3.8, 4.5, 2.1 and 4.0 t ha^{-1} in 1988, 1989, 1990 and 1991 respectively while achene oil content was 49.0, 44.7, 47.5 and 51.3% over the same years.

Early flaming cost (table 6), with a gas consumption of 60 kg ha^{-1}, was similar to chemical control (Lit 139.000 ha^{-1}). The cheapest treatment was hoeing with Lit 70.000 ha^{-1}.

Table 6 - Costs of treatments reffered to 1991 prices.

Treatments	Application time ($h\ ha^{-1}$)	Commercial preparation	Rate ($kg\ ha^{-1}$)	Cost ($Lit\ kg^{-1}$)	Treatment cost ($Lit\ ha^{-1}$)
Hoeing	2.0	-	-	-	70.000
Flaming I	1.8	LPG	60.0	1.100	129.000
Flaming II	2.2	LPG	88.0	1.100	173.000
Chemical	1.0	Patoran+	1.2	28.000	
weed control		Gesagard 50	2.0	35.000	139.000

Discussions and conclusion

The present study gives some indications about flaming in sunflower. Different effects of the two times of flaming application on grasses and broadleaves are attributed to the different morpho-physiological characteristics of species and to the time of their emergence. According to the results of Vester (1984) grasses are sensitive to flaming also during the latest growth stages, while broadleaves are sensitive to early thermal treatments when most of the species have 2-4 true leaves.

In 1988, the absence of *C. album* was due to the late sowing of sunflower. This fact also caused a low infestation levels of the other weed species during the same year of experiment. The low effectiveness of flaming on *S. nigrum* in 1990 is attributed to the high biomass of *C. album* which can have shielded the first species from flame.

The mean increase of viable weed seed number recorded after ploughing (82 days after crop harvest) could be associated both to the breaking of dormancy and selective effects on germination of some species promoted by crop residues (Purvis *et al.*, 1985). The increase of viable weed seed number recorded in flamed plots is due to the previous crops included in the rotation. Soybean, corn and wheat were included in a four-year rotations in which weed control was carried out by flaming. The low effectiveness in controlling weed density of thermal treatments, compared to herbicide or hoeing application, caused an increase of weed seed in the soil.

Yields and achene oil content showed that sunflower is able to give high performances even when weed infestation is as high as 137 plants per m^2. Similar results were also reported by Pirani (1988, 1989). Thus, with regards to sunflower growing in the same conditions of the present experiment, herbicide application can be replaced by hoeing or flaming in order to avoid risks of pollution.

In conclusion, thermal treatment can be considered a good technique to include in integrated or completely chemical-free methods for the control of weeds in sunflower. In order to reduce application costs by 40%, on-row flaming and inter-row hoeing could be combined in one single operation. Moreover, further researches are necessary for the setting-up of machines and for the effectiveness of flaming in different areas of cultivation.

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